Status of E949 gamma analysis
$K^+ \to \pi^+ \gamma\gamma$

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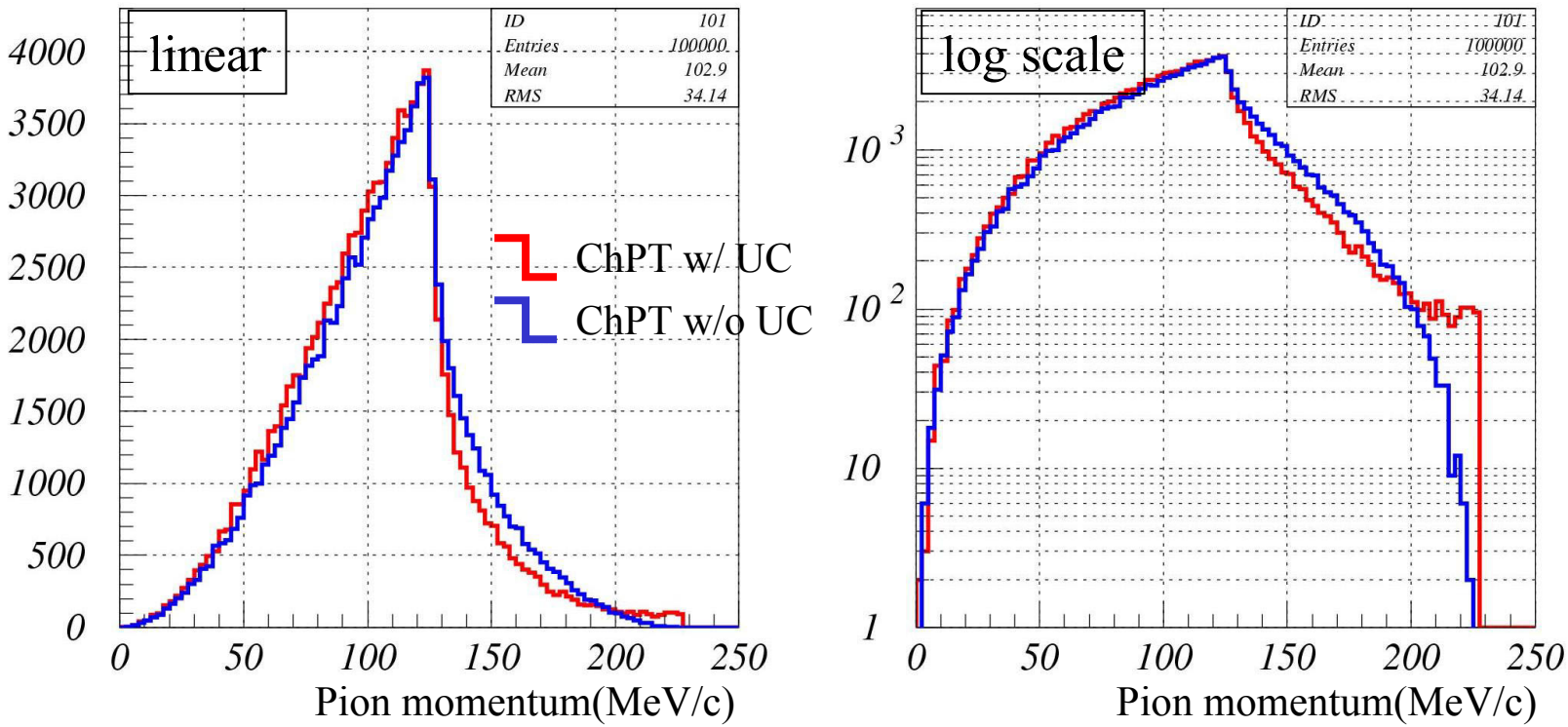
outline

1. Introduction
2. Background Study (2/3 sample)
3. Sensitivity Calculation
4. Summary and Future

Theoretical Interest

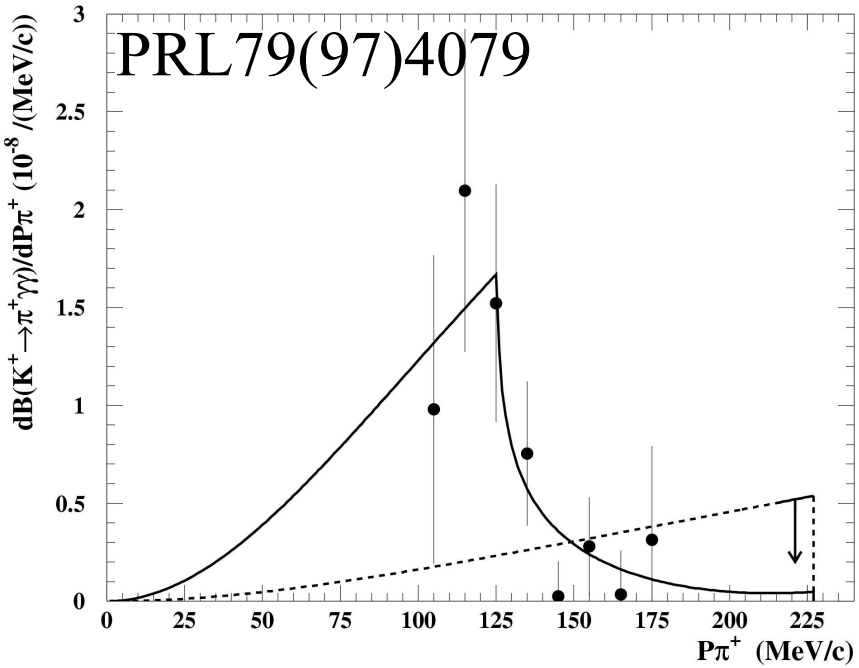
- Chiral Perturbation Theory (ChPT) predicts a peculiar momentum spectrum to the $K^+ \to \pi^+ \gamma\gamma$ decay.
- Higher order correction, unitarity corrections (UC), predicts a non-zero amplitude at the kinematic end point.



Experimental Status

- *Definition*
  - $\pi^+\gamma\gamma(1): P_{\pi^+} > 215 MeV/c$ (above $K_{\pi 2}$)
  - $\pi^+\gamma\gamma(2): P_{\pi^+} < 180 MeV/c$ (below $K_{\pi 2}$)
- *Results from E787*
  - $Br(\pi^+\gamma\gamma(1)) < 5.0\times10^{-7}$ (90% C.L.)
    No event was ovserved.
  - $Br(\pi^+\gamma\gamma(2))$
    $= (6.0 \pm 1.5(stat.) \pm 0.7(syst.))\times10^{-7}$
    31 events with background 5.1 ± 3.3.
- *Best fit to the data*
  - $Br(\pi^+\gamma\gamma) = (1.1 \pm 0.3(stat.) \pm 0.1(syst.))\times1$

  $\hat{c} = 1.8 \pm 0.6$



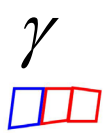
- The measured spectrum verified the ChPT prediction.
- The data favors UC but is still consistent w/o the correction.

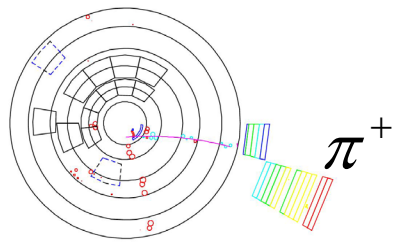
$K^+ \to \pi^+ \gamma\gamma$ in E949

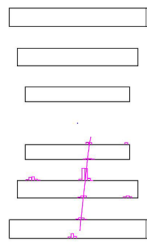
- In order to prove the existence of the UC in ChPT, new $K^+ \to \pi^+ \gamma\gamma$ (1) trigger was installed.

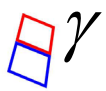
– $KB \cdot DC \cdot IC \cdot T \bullet 2 \cdot (6_{ct} + 7_{ct}) \cdot (8_{ct} \cdots 16_{ct}) \cdot \overline{(18_{ct})} \cdot \overline{(19_{ct})} \cdot \overline{(20_{ct})} \cdot \overline{(21_{ct})} \cdot$
$BVL \cdot BV \cdot HEX \cdot \overline{ECL0} \cdot L1.n$

- Kaon stop and decay in the target
- longer range than $K_{\pi 2}$
- veto BVL hits in CT sectors
- γ's in Barrel
- PV in RS and EC









Event Display

RUN 49977
EVENT 1

- from run 49036 (2002-Apr.-24) to the end of the run (2002-June-9).
- ~25ev/spill, no prescale.
- accumulated KBlive : ~1.192e12.

Analysis Status

- *Updated points since the last meeting*

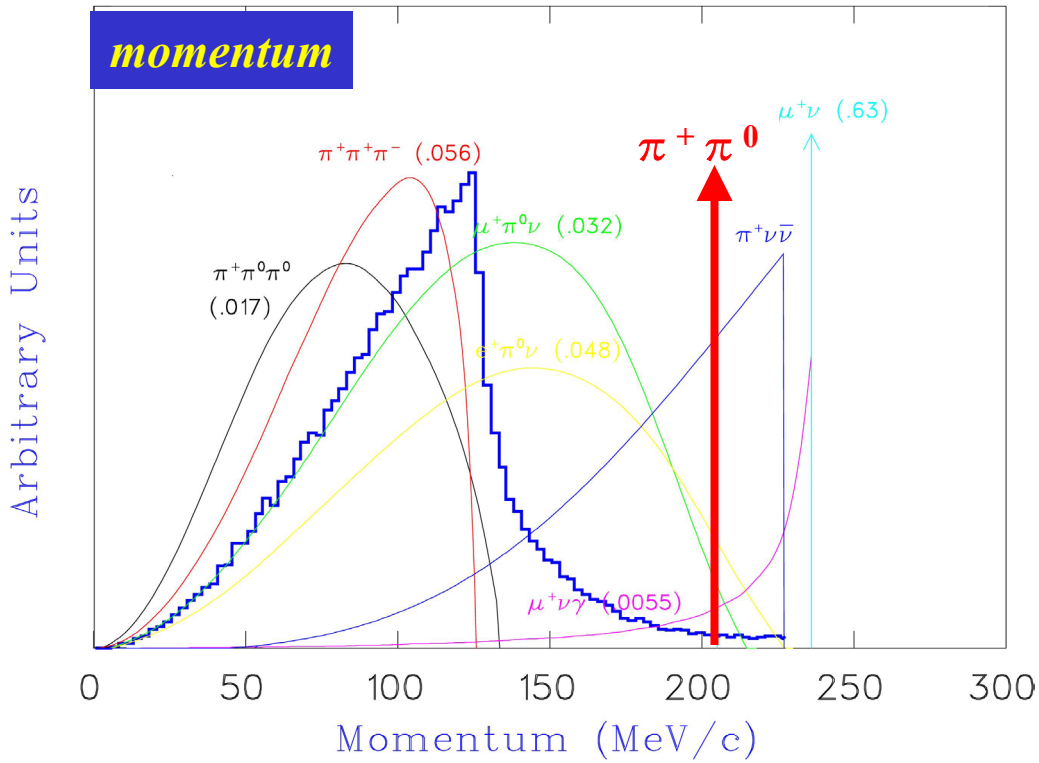
- Background Study (2/3 sample)

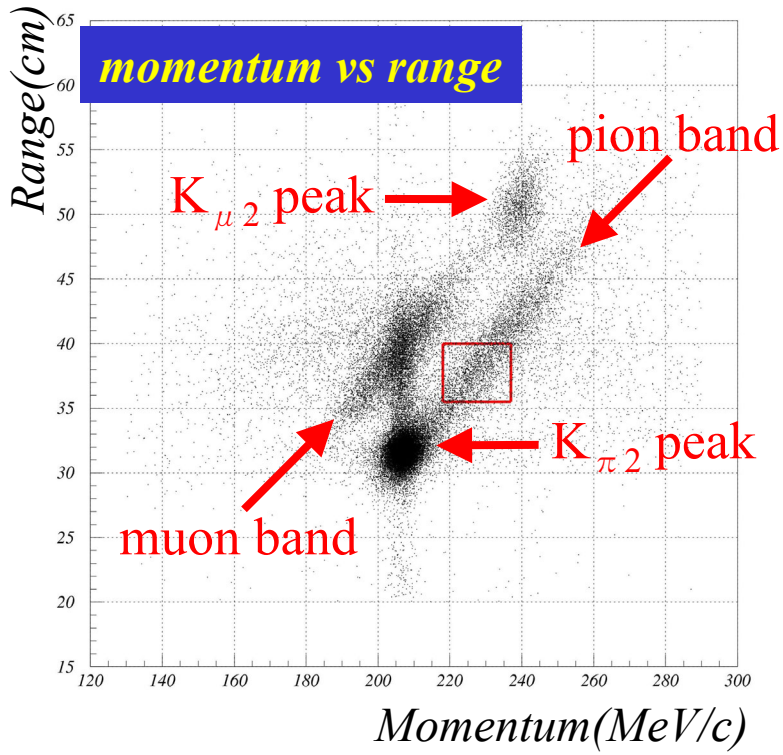
  Note : Recently, a bug was found in the BVCLS cut.
  So number of background level in this talk might be changed,
  but the change is expected to be small.

- Outside-the-Box Study

- Sensitivity Calculation

Background Sources





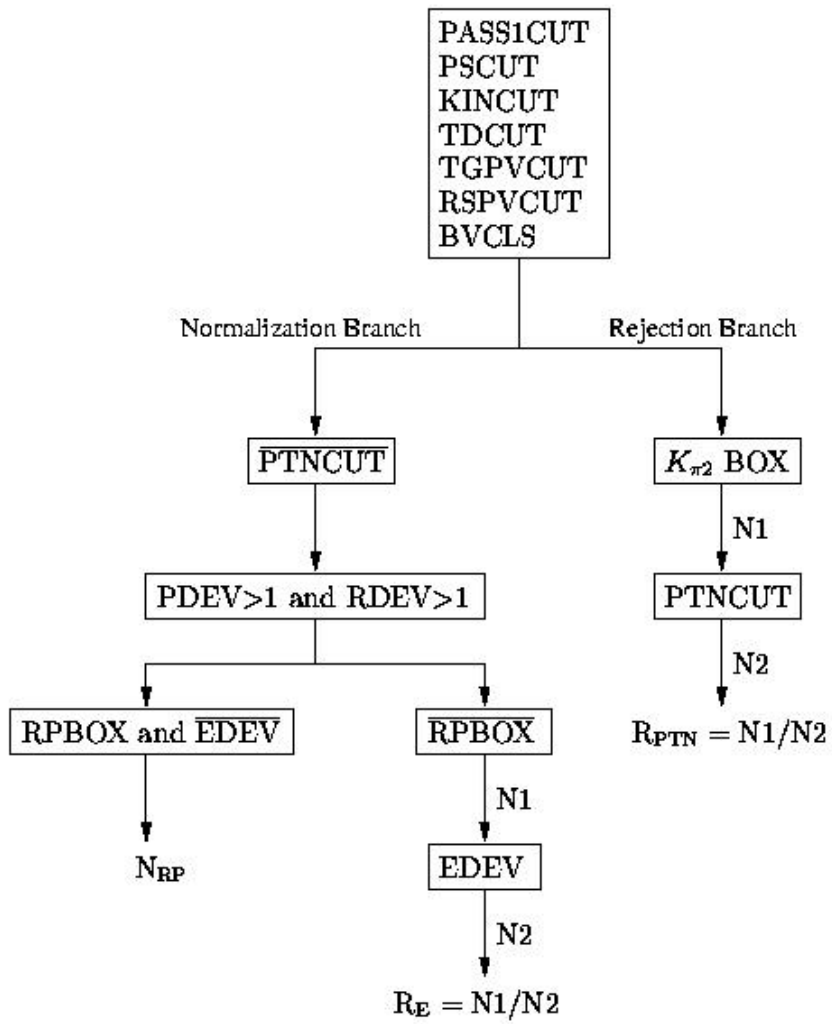
Source	Mechanism	Main Tool
$\pi^+\pi^0$	same final state	Photon cuts
$\pi^+\pi^0$ due to the photon overlapping the π^+	same final state if two photons from signal are fused	Range Stack dE/dx cut
Muon w/ photon	particle miss ID	Look for $\pi \to \mu \to e$ chain
Beam related	Kaon decay-in-flight	Beam counter cuts

Kpi2 Background

- The Kpi2 decay is one of the major background sources because the final states are identical to pigg.

- The two cuts for the bifurcated method are :
  1) box cuts on the charged track
     and
  2) photon cuts

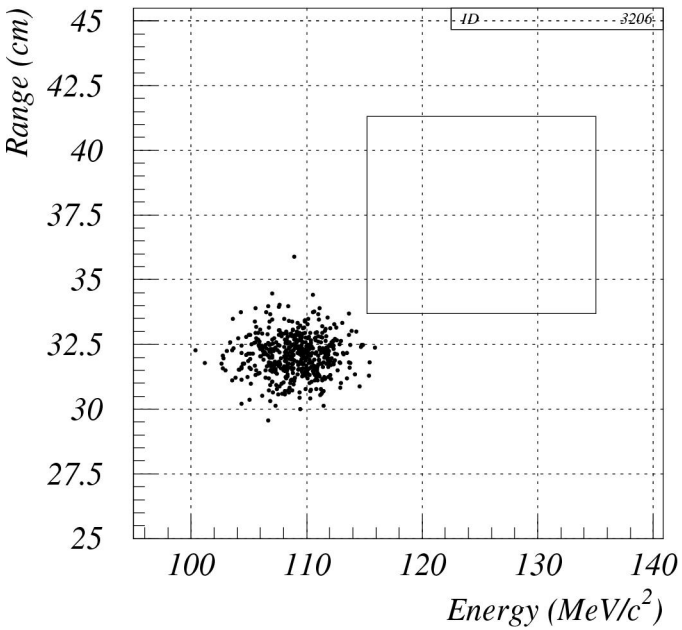
- The 2nd bifurcation between RPBOX cuts and the EBOX cuts was performed in order to estimate the number of events in the normalization branch.



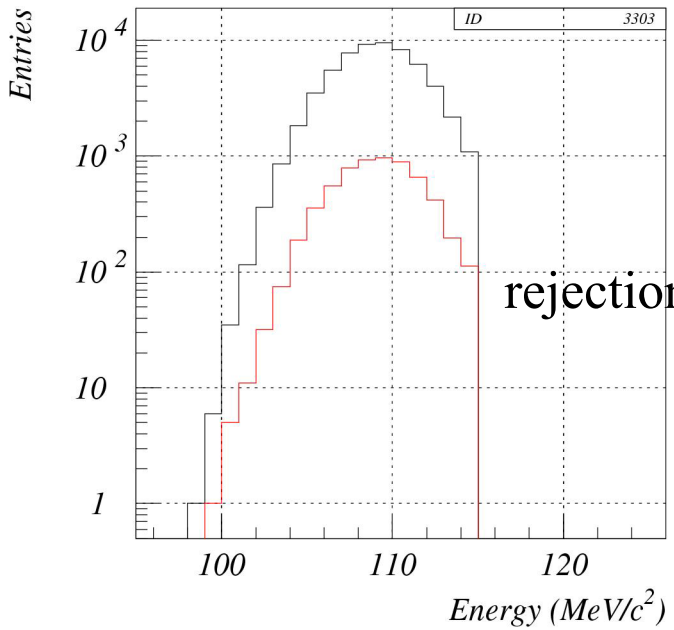
$$N_{norm} = \frac{N_{RP}}{R_E - 1} \qquad N_{K_{\pi 2}} = \frac{N_{norm}}{R_{PTN} - 1}$$

Kpi2 Background(2/3)

normalization branch



rejection branch



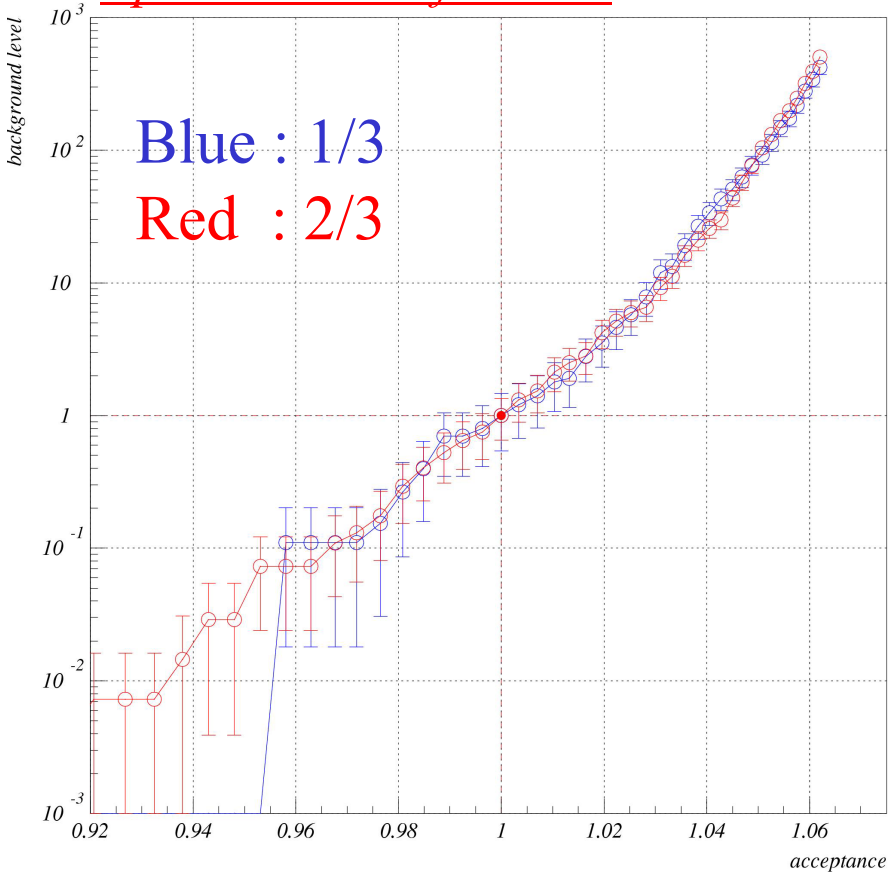
rejection = 9.81

- # of events in the norm. branch from 2nd bifurcation is 0.134
- The Photon cuts rejection is 9.81.

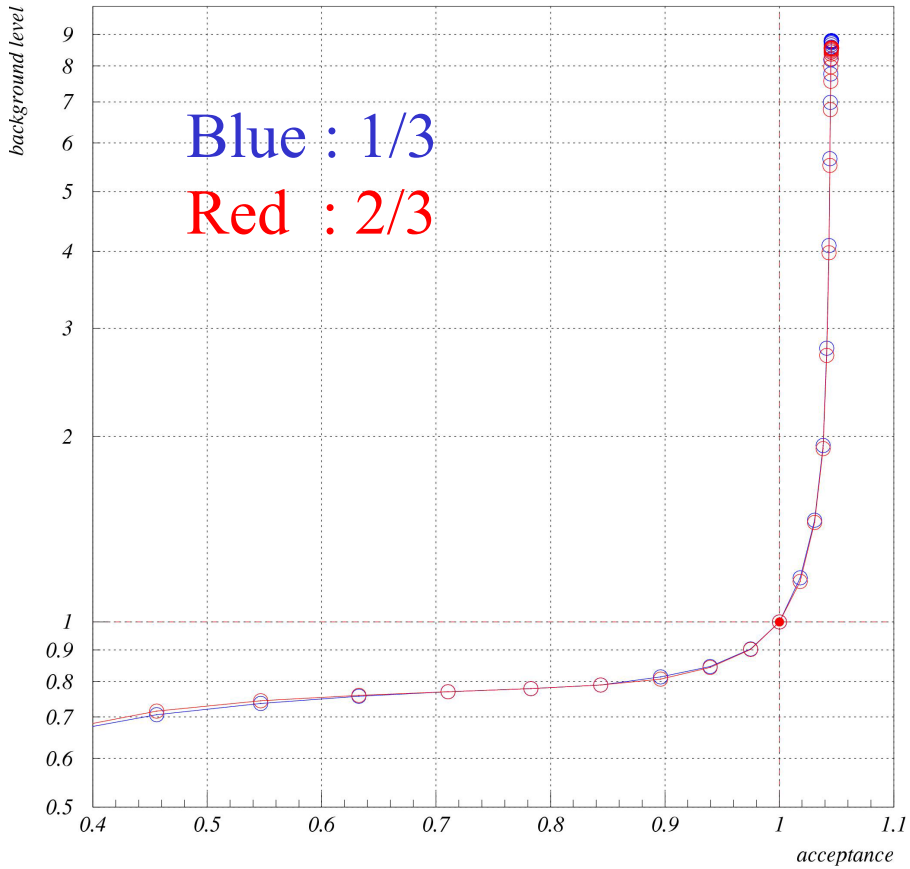
# of Kpi2 backgrounds = 0.015 ± 0.005

Kpi2 Functions

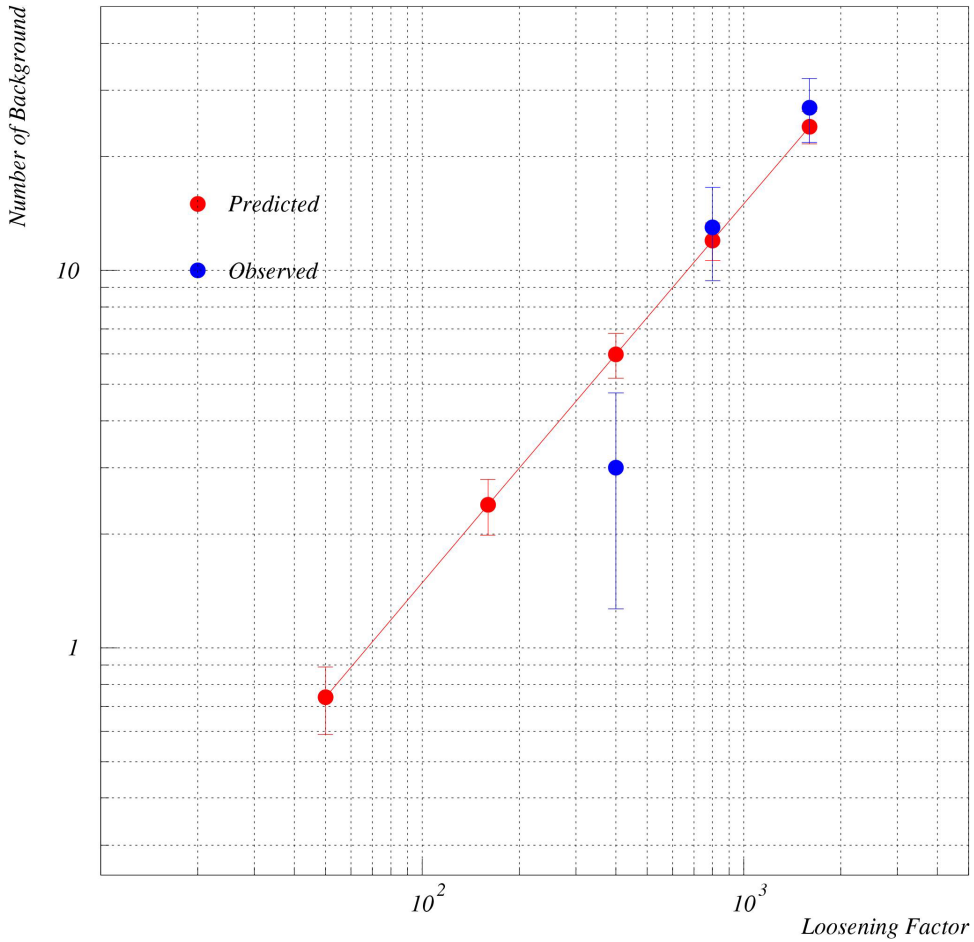
Kpi2 kinematic function



Photon cut function



Outside-the-Box Study(Kpi2)



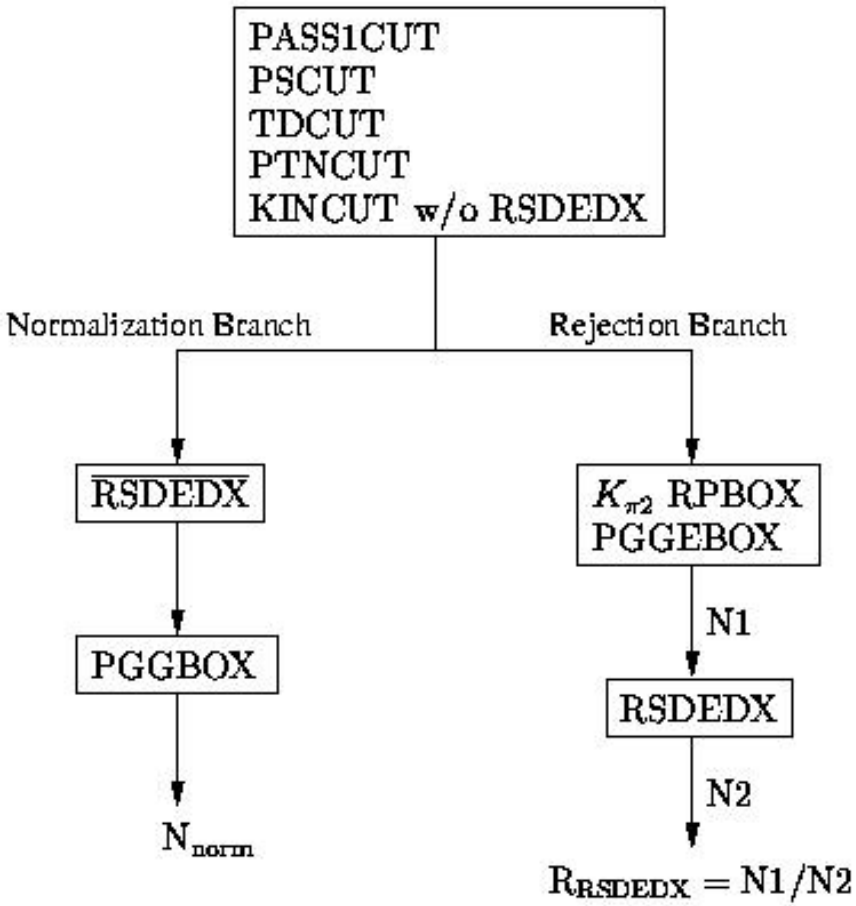
KINxPV	Predicted	Observed
10x5	0.74	0
20x8	2.39	0
50x8	5.99	3
100x8	11.99	13
200x8	23.99	27

Good agreement between observed and predicted number of events can be seen.

Overlapping Photon Background

- Two photons from pigg could be detected as a single cluster in Barrel. On the other hand, the higher energy photon from the pi0 in Kpi2 decays tends to be emitted to the opposite direction to the pi+ and lower energy photon could be overlapped to the pi+.

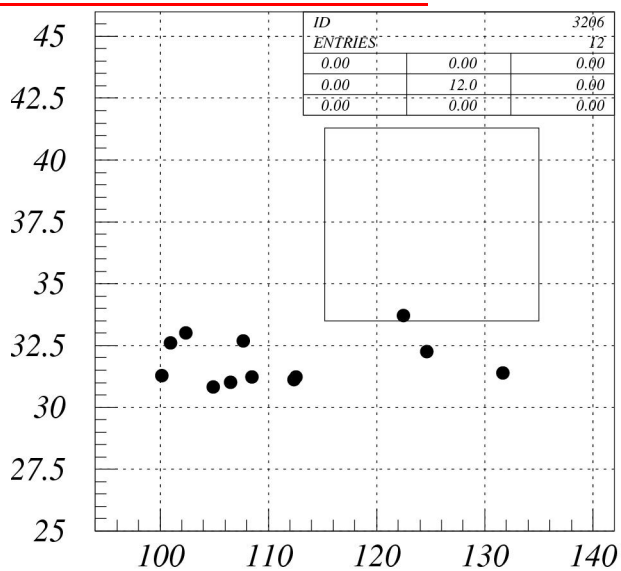
- The two cuts for the bifurcated method are :
  1) box cuts on the charged track
     and
  2) Range Stack dE/dx cut



$$N_{Overlap} = \frac{N_{norm}}{R_{RSDEDX} - 1}$$

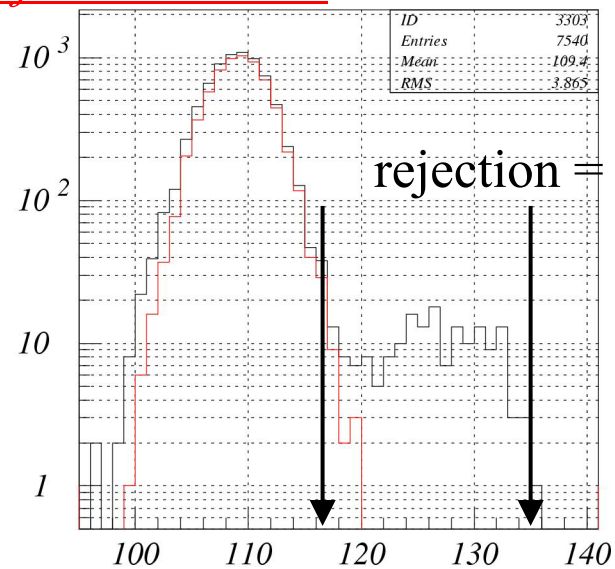
Overlapping Photon Bkgd.(2/3)

normalization branch



rtot vs etot PGGBOX

rejection branch



rejection = 21.0

etot KPI2BOX

- One event remained in the signal-box.
- The RSDEDX rejection is 21.0.

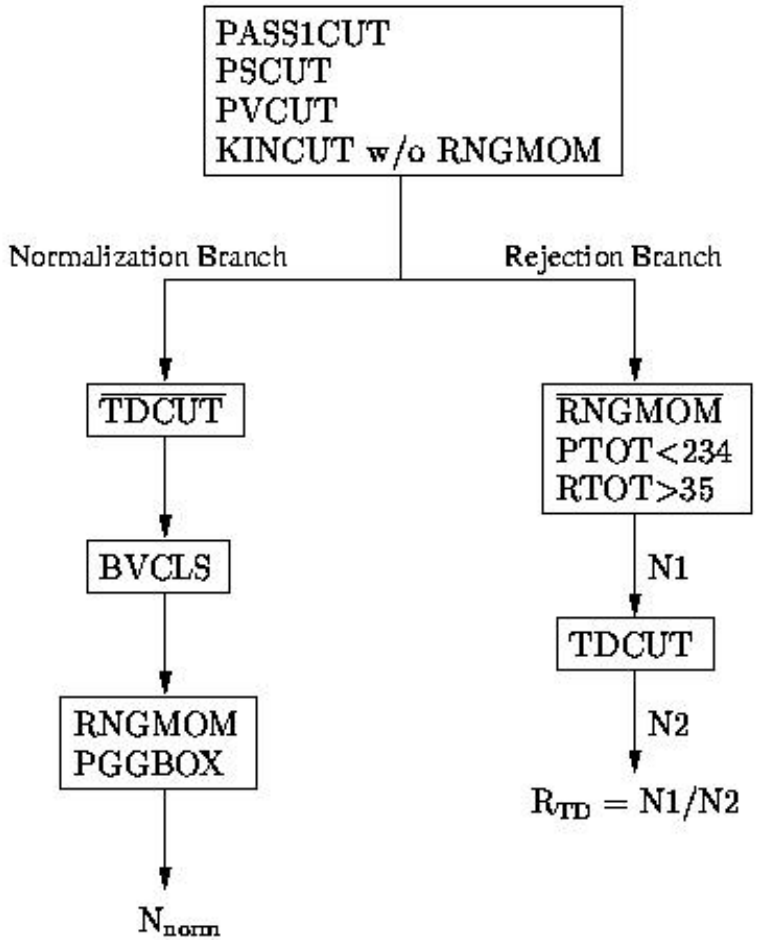
# of overlapping photon backgrounds = 0.050 ± 0.050

Muon Background

MuonBackgroundStudy

- The kaon decays with muon and a photon (or photons) in the final state, such as the Km2g or Km3 decays, could be a source of background. The Kpi2 decay whose pi+ decays in flight is also categorized as the muon background.

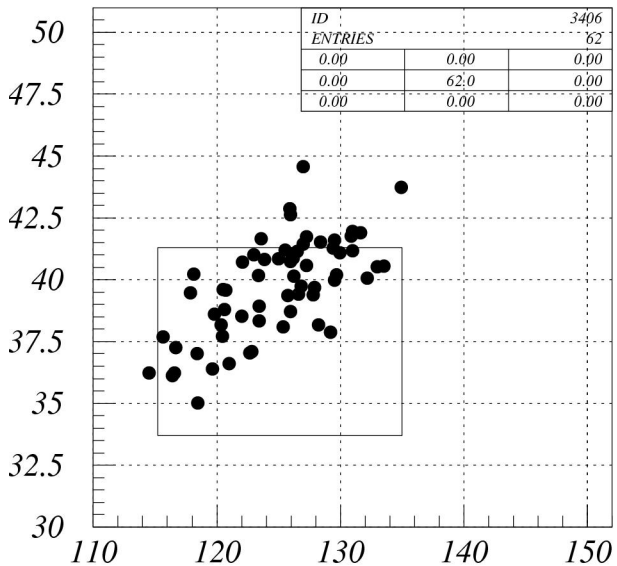
- The two cuts for the bifurcated method are :
  1) box cuts on the charged track
     and
  2) TD cuts



$$N_{Muon} = \frac{N_{norm}}{R_{TD} - 1}$$

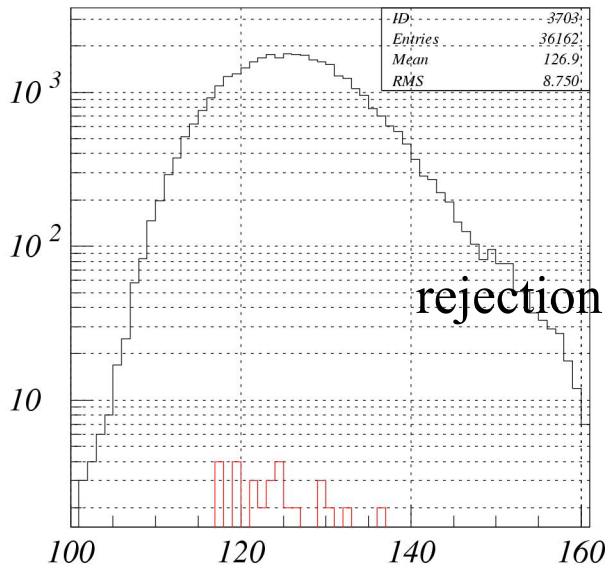
Muon Background(2/3)

normalization branch



rtot vs etot PGG-P-BOX

rejection branch



etot PV muon-band

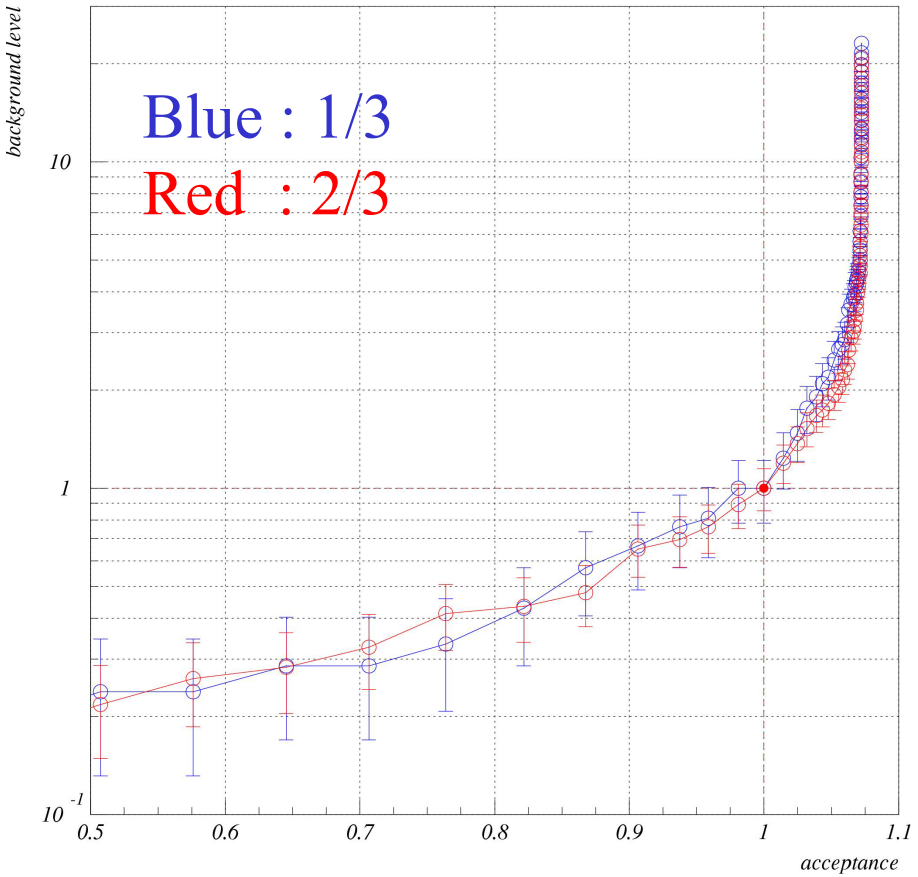
rejection = 753.4

- 46 events remained in the signal-box.
- The TDCUT rejection is 753.4 for band events.

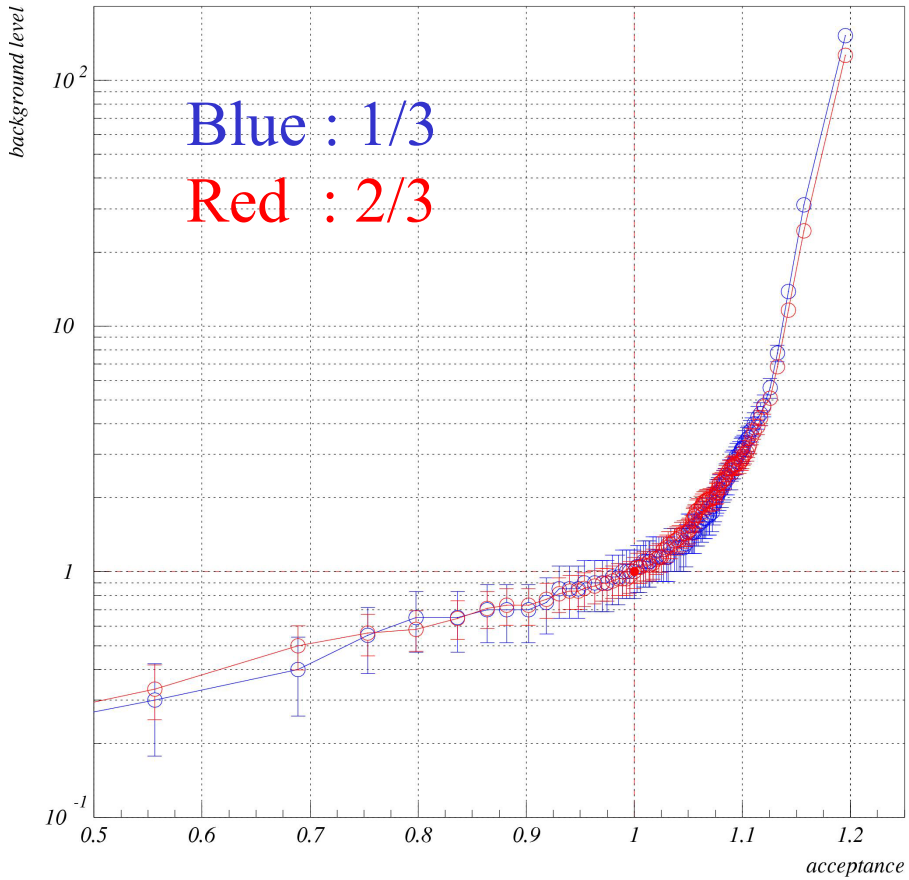
# of muon backgrounds = 46/(753.4-1) = 0.061 ± 0.013

Muon functions

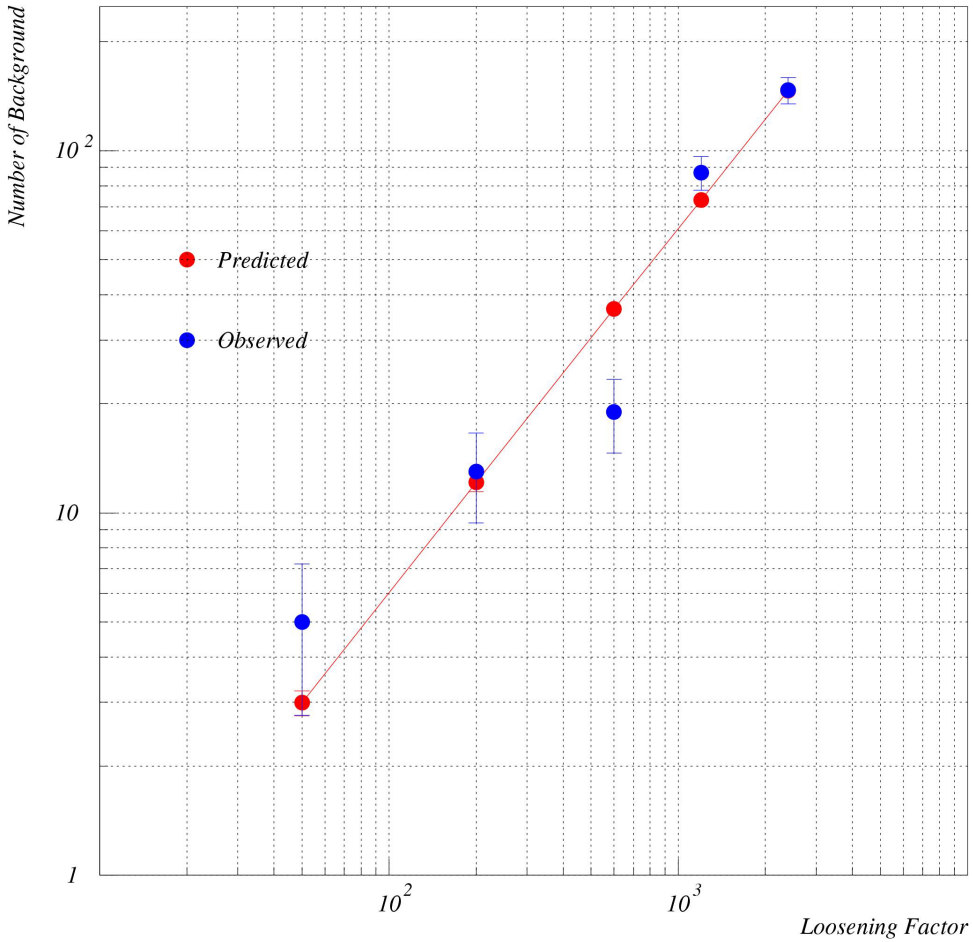
Muon kinematic function



TD cut function



Outside-the-Box Study(Muon)



TDxKIN	Predicted	Observed
10x5	2.99	5
20x10	12.14	13
40x15	35.54	19
80x15	73.14	87
120x20	146.34	147

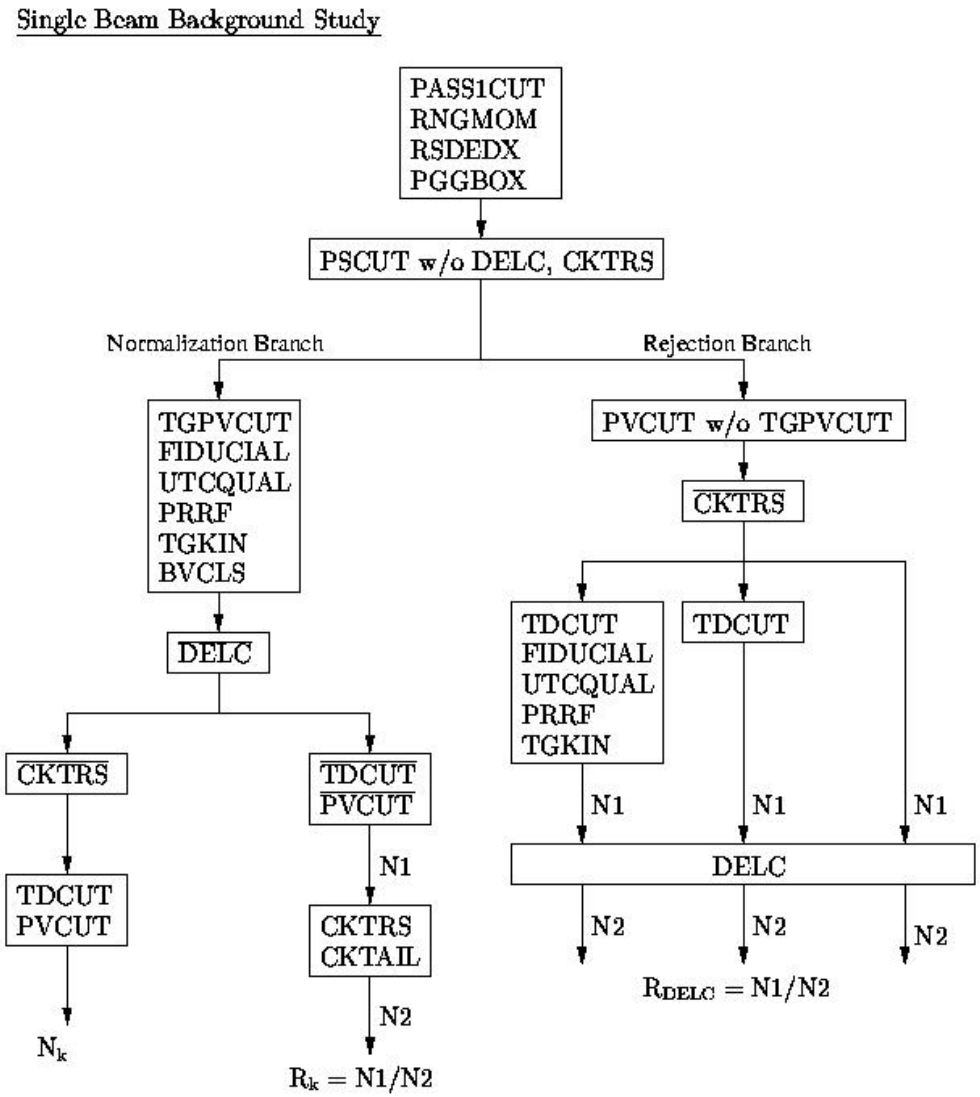
Good agreement between observed and predicted number of events can be seen.

Single Beam Background

- The kaon decay-in-flight to pi+pi0 is a source of background from the single kaon beam, because a pion fror the Kpi2 d.i.f., being Lorentz-boosted could satisfy the pigg box cuts .

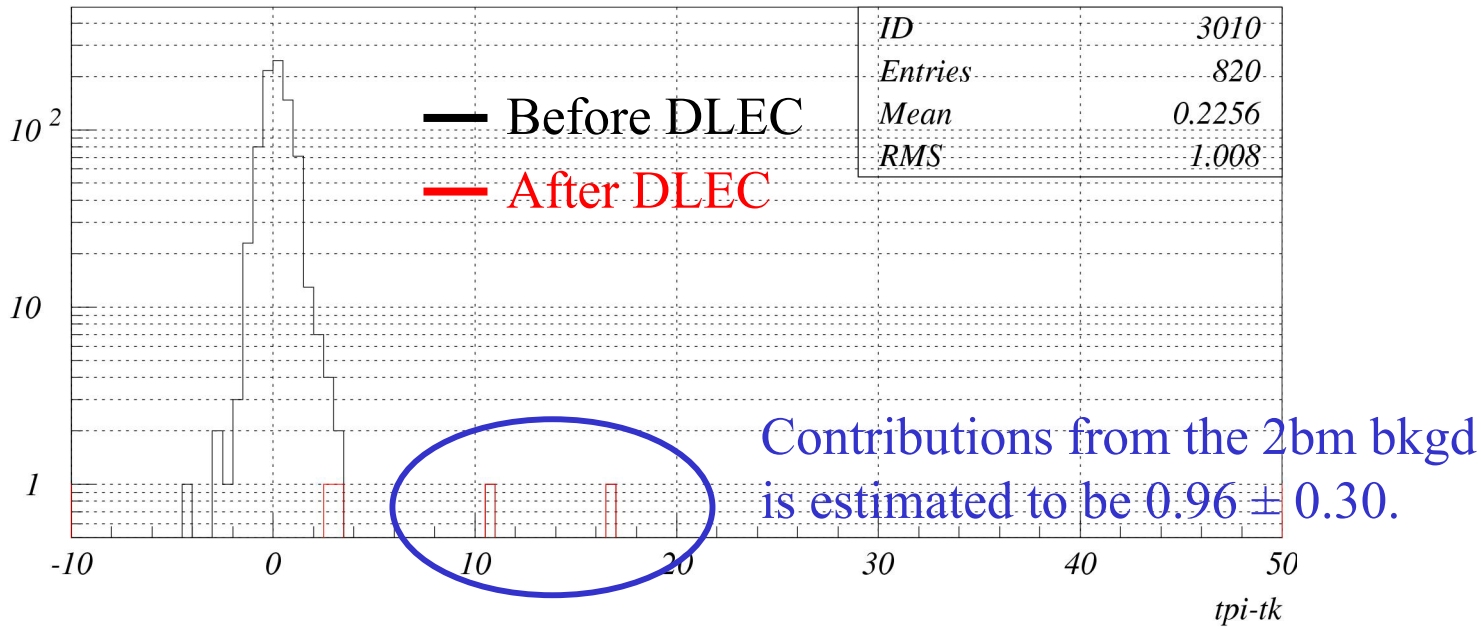
- The two cuts for the bifurcated metho are:
  1) offline delayed coincidence
     and
  2) timing cuts on the Kaon Cerenkov

- The DELC rejection is measured in three ways and the smallest value is conservatively used.



Single Beam Background(2/3)

- tpi-tk distribution tagged by the inverted CKTRS(loose setup cuts)

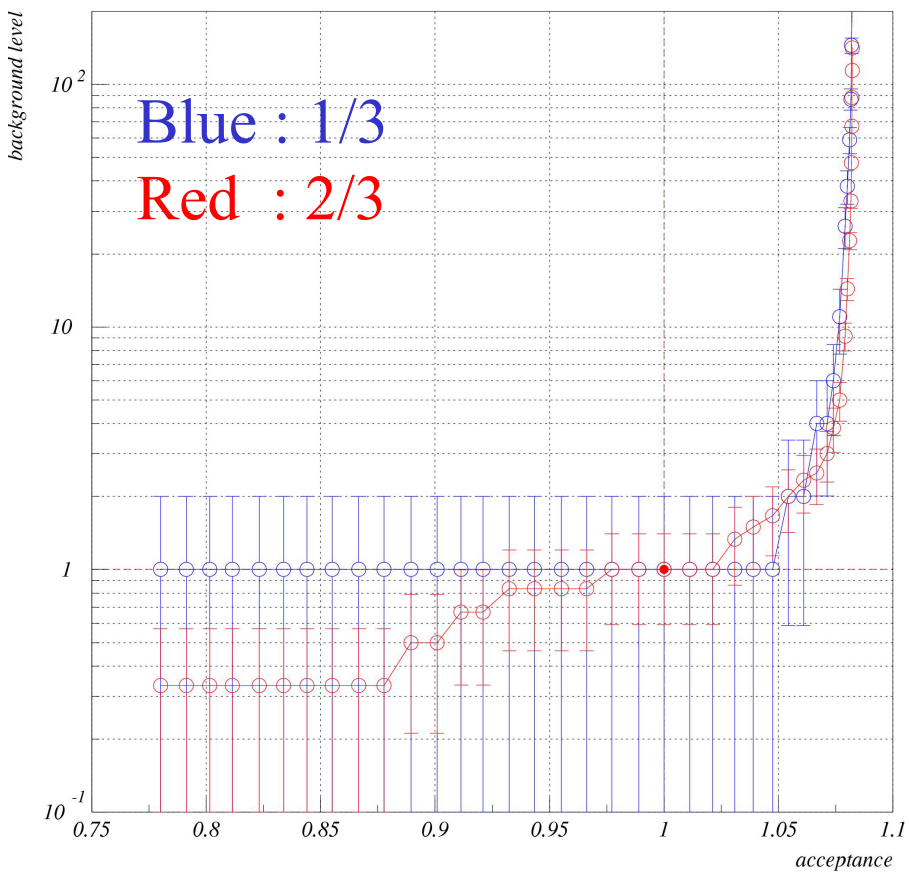


- # of events in the norm. branch from 2nd bifurcation is 3.4
- The DELC rejection is 255.0

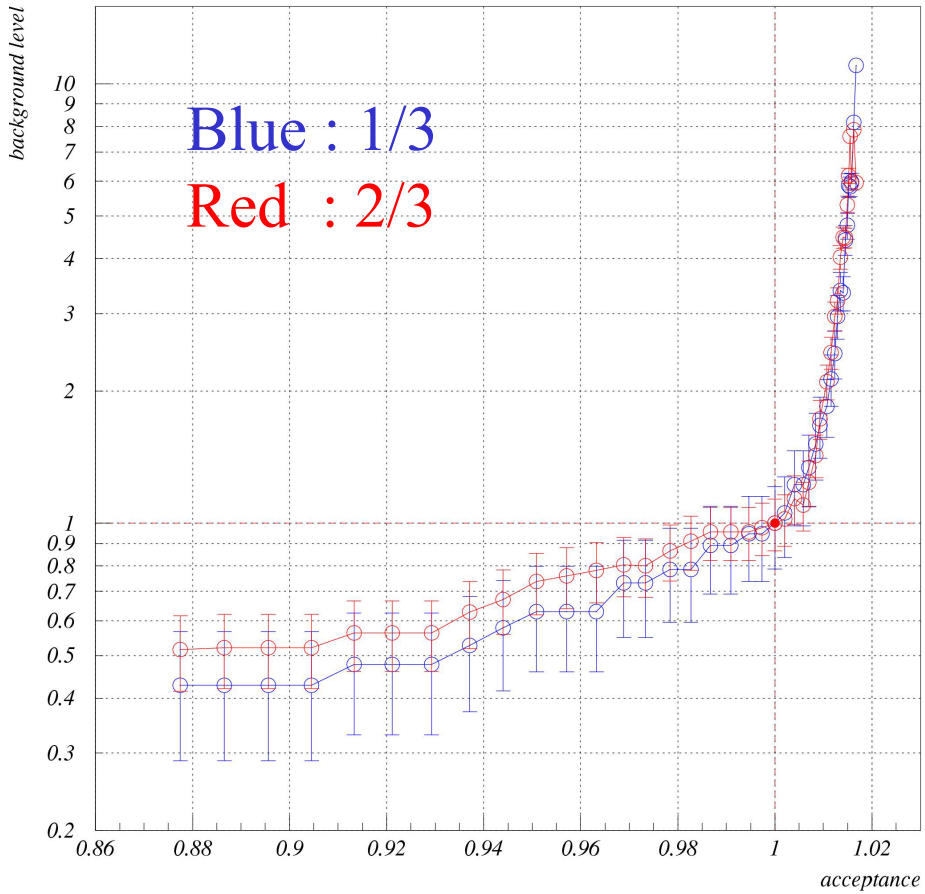
# of single beam backgrounds = 0.013 ± 0.007

Single Beam Functions

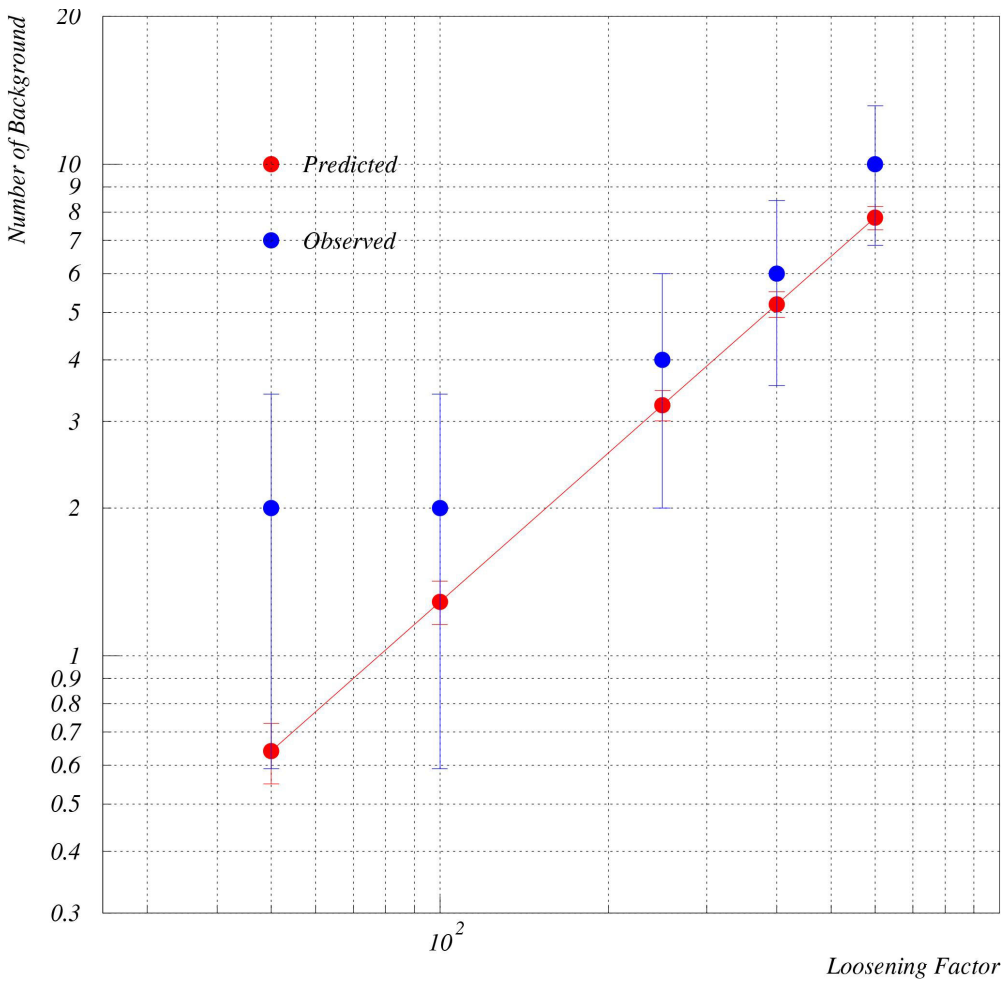
Muon kinematic function



TD cut function



Outside-the-Box Study(1bm)

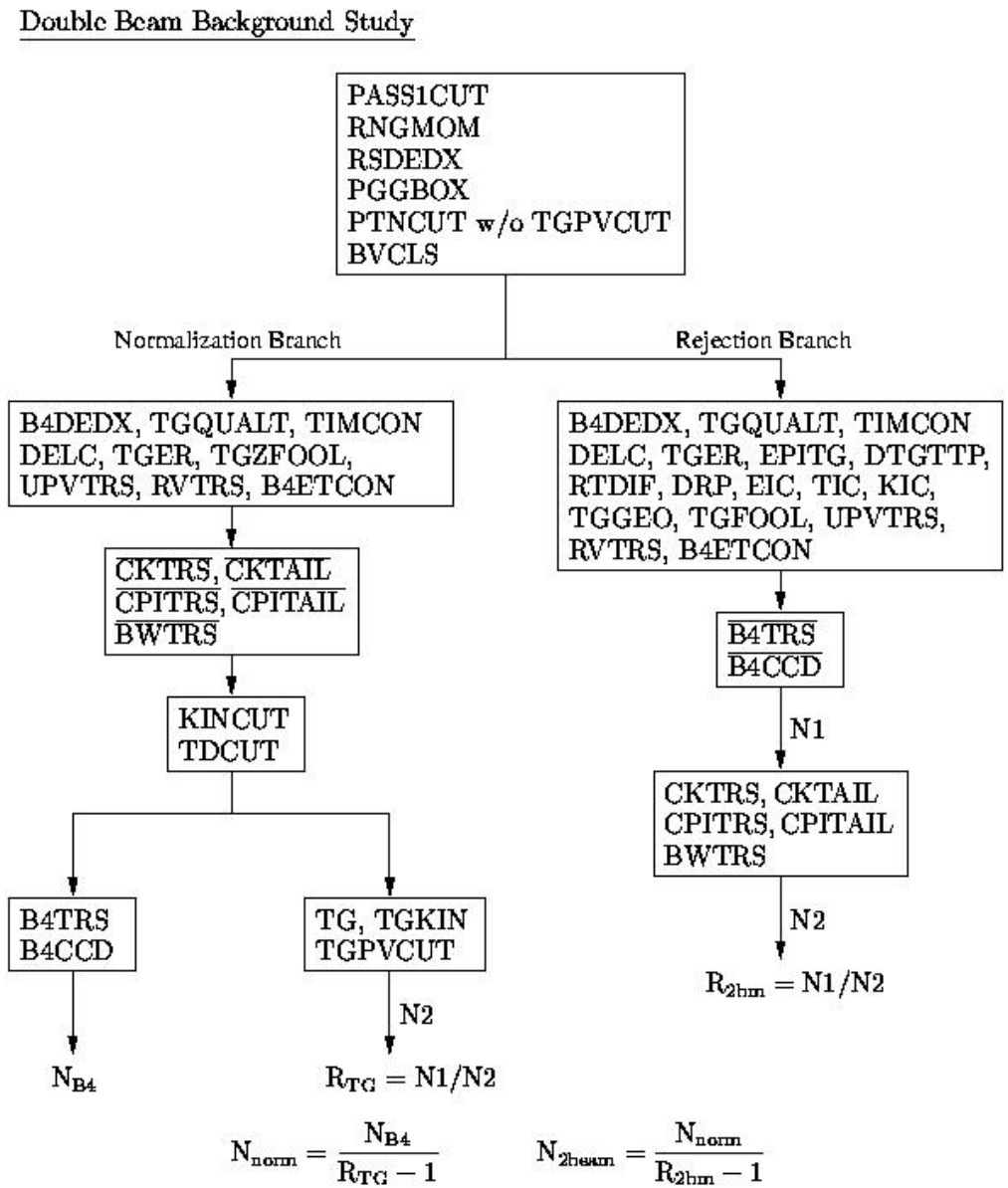


DCxCK	Predicted	Observed
10x5	0.64	2
20x5	1.29	2
50x5	3.24	4
80x5	5.19	6
120x5	7.79	10

Good agreement between observed and predicted number of events can be seen.

Double Beam Background(2/3)

- There are two types of double beam background: 1) Primary kaon enters the target; secondary kaon follows a decays in flight to pi+pi0, and the pi comes to rest in the RS. 2) Primary kaon enters the target and decays in flight to pi+pi0; secondary pion follows and is scattered into the RS.
- The two cuts for the bifurcated method are :
  1) CKTRS, CKTAIL, CPITRS, CPITAIL and BWTRS and
  2) B4TRS and B4CCD
- The 2beam background is estimated to be 0.0053 (90%C.L.).



Summary of Background Study

Source	1/3	2/3
Kpi2	0.028 ± 0.013	0.023 ± 0.008
Overlap	< 0.061(90%C.L.)	0.075 ± 0.075
Muon	0.069 ± 0.021	0.092 ± 0.020
1bm	0.006 ± 0.006	0.020 ± 0.010
2bm	< 0.009(90%C.L.)	< 0.005(90%C.L.)
Total	0.11 ± 0.03	0.21 ± 0.08

- Note that these numbers have already been scaled to the full sample (i.e. multiplied by a factor of 3 for the 1/3 sample and 1.5 for the 2/3 sample).
  The 90%C.L. upper limits were unscaled.

f_s Calculation

- The stopping fraction was measured by using the Kpi2 events in the pigg trigger.

$$f_s = \frac{N_{K_{\pi 2}}}{\varepsilon T \bullet 2 \cdot IC(K_{\pi 2}) \cdot Br(K_{\pi 2}) \cdot K_{Blive} \cdot A_{K_{\pi 2}} \cdot A_{K_{\pi 2}}^{UMC}}$$

$$= \frac{212709}{0.936 \cdot 1.19 \times 10^{12} \cdot 0.212 \cdot 0.0187 \cdot 0.632 \times 10^{-5}}$$

$$= 0.761 \pm 0.023$$

Expected Signal Event

- The number of expected signal events is calculated to be

  # of expected signal events

  = Br(pigg>200MeV/c) * KBLive * fs *T2IC* Acceptance

  = 1.178e-8 * 1.192e12 * 0.761 * 0.936*1.693 e-4

  = 1.69 event

Summary and Future

- The number of expected signal events is calculated to be 1.69 while the background level is estimated to be 0.21 ± 0.08. In terms of the background study, we are ready to open the box.

TODO

- Cross check for the fs calculation; will be performed using the km2 decays in the km21 trigger.

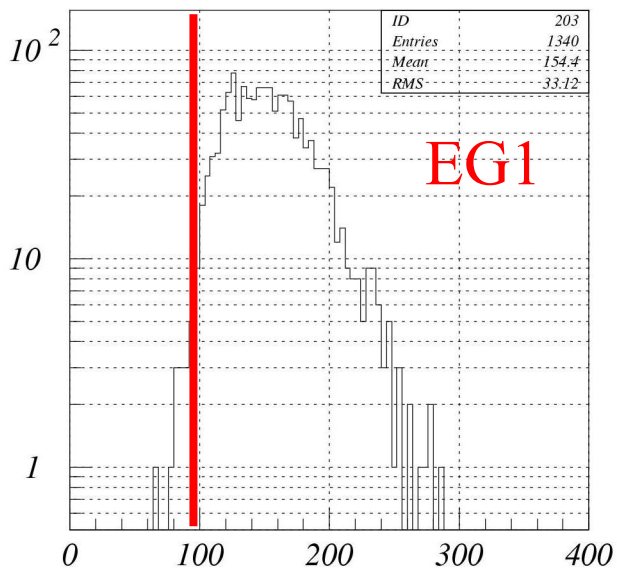
Backup Slides

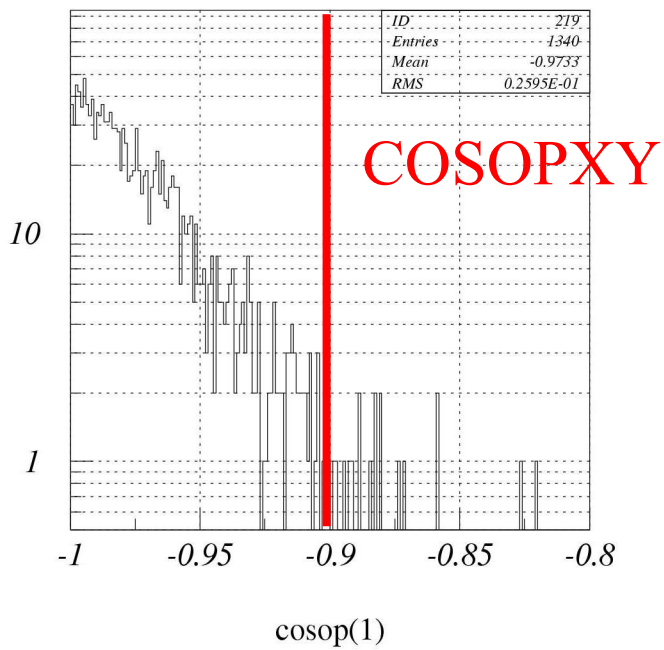
Cuts Description

- SETUP
  RDTRK, TRKTIM, UTC, RANGE1, STLAY,
  RSHEX, UTC1, RDUTM, RSHEX2,
  COS3D, ITGQUALT0, LAY1617, TGPVCUT
- PSCUT02
- KINCUT01
- TDCUT
- BVCLS
  EG1, DIPG, COSOPXY, COSOPZ, BVCTIME
- RDPVCUT (RDPSHCUT)
- PVCUT
  Standard PVCUT except for the BV, BVL and RS
  TZMAX, ERAT vs COSGG

BVCLS

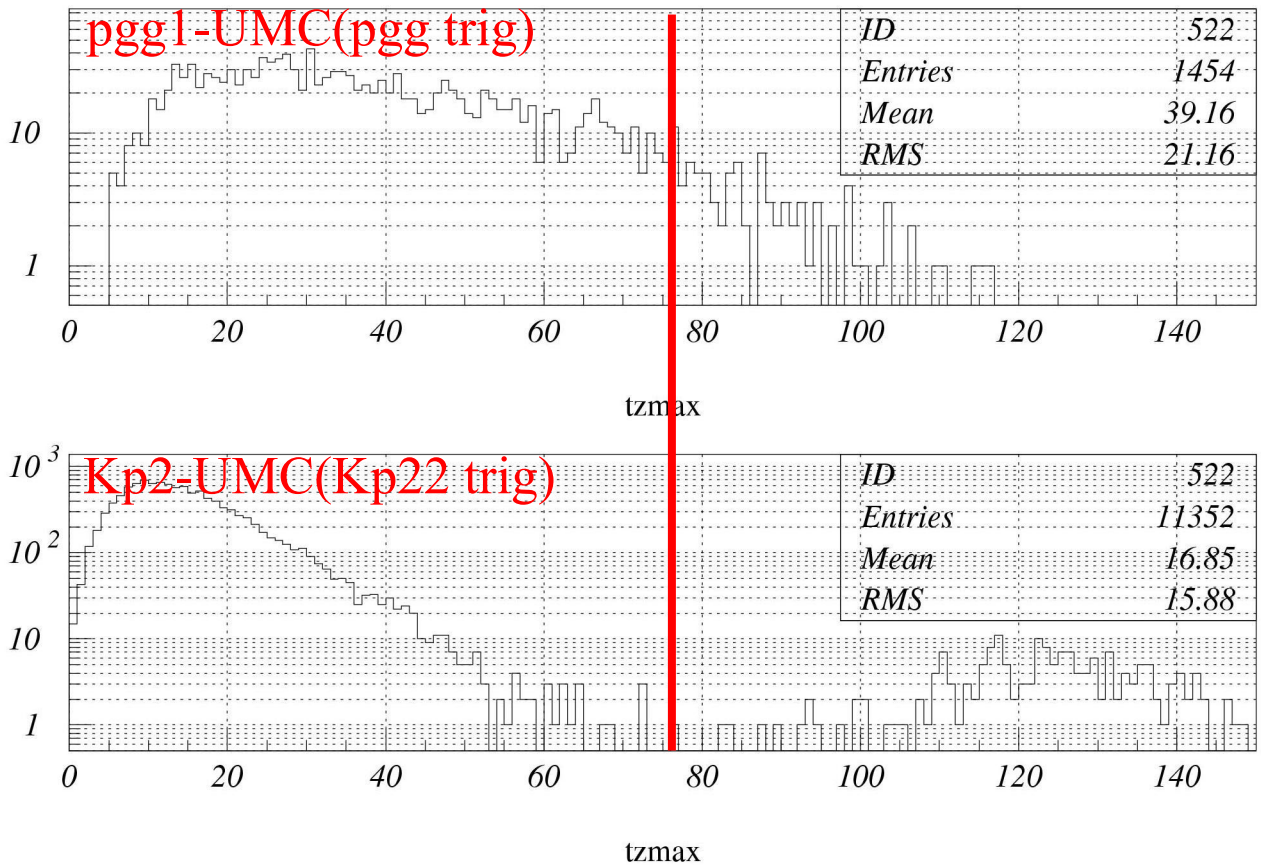
- EG1 : the energy of the highest-energy cluster(γ_1) is > 100 MeV/c.
- DIPG : $|\cos(\theta_{\gamma 1})| < 0.6$, where $\theta_{\gamma 1}$ is the dip angle of γ_1.
- COSOPXY : azimuthal opening angle is > 155deg.
- COSOPZ : polar opening angle is > 155deg.
- BVCTIME : the timing of 0.0±2.0nsec.





PVCUT(1)

- TZMAX : Veto the γ_1 cluster if the maximum discrepancy among TDC Z-measurements is > 75 cm.



PVCUT(2)

- ERAT vs COSGG : cut on the photon energy ratio vs opening angle between two photons.

$$\frac{E_{\gamma_2}}{E_{\gamma_1}} = \frac{E_0 - \sqrt{E_0^2 - \dfrac{2M_{\gamma\gamma}^2}{1-\cos(\theta_{\gamma\gamma})}}}{E_0 + \sqrt{E_0^2 - \dfrac{2M_{\gamma\gamma}^2}{1-\cos(\theta_{\gamma\gamma})}}}$$

where

$$E_0 = \frac{M_{K^+}^2 - M_{\pi^+}^2 + M_{\gamma\gamma}^2}{2M_{K^+}}$$

current cut position

$$M_{\gamma\gamma} = 100 MeV/c^2$$